

### Thermal consequences of proposed poly shielding inside the MC can

An early proposal for the SCDMS cryostat has a substantial block of poly located inside the MC can (Figure 1). The detectors would reside inside the poly block. The presence of the poly raises an obvious thermal question. How much time does the poly add to system cool down? Dan Bauer indicates that the poly at SUF added 10 days to the cool down time from 4 K to base. Dan also notes that the poly was heat sunk to the CP stage (50 mK) by interspersing thin sheets of copper. Dan believes that the SUF poly mass was about 8 kg. The proposed SCDMS poly mass is about

$$\left[ \left( \frac{\pi}{4} \right) \times (29^2 - 21^2) \times 17 + \left( \frac{\pi}{4} \right) \times 29^2 \times (25 - 17) \right] \text{in}^3 \times \frac{58.8 \text{lb}}{\text{ft}^3} \times \frac{1 \text{ft}^3}{1728 \text{in}^3} \times \frac{1 \text{kg}}{2.20462 \text{lb}} = 164 \text{kg}.$$

Thus if the 10 day cool down time scales with mass, the 20x heavier 164 kg of poly will not be practical.

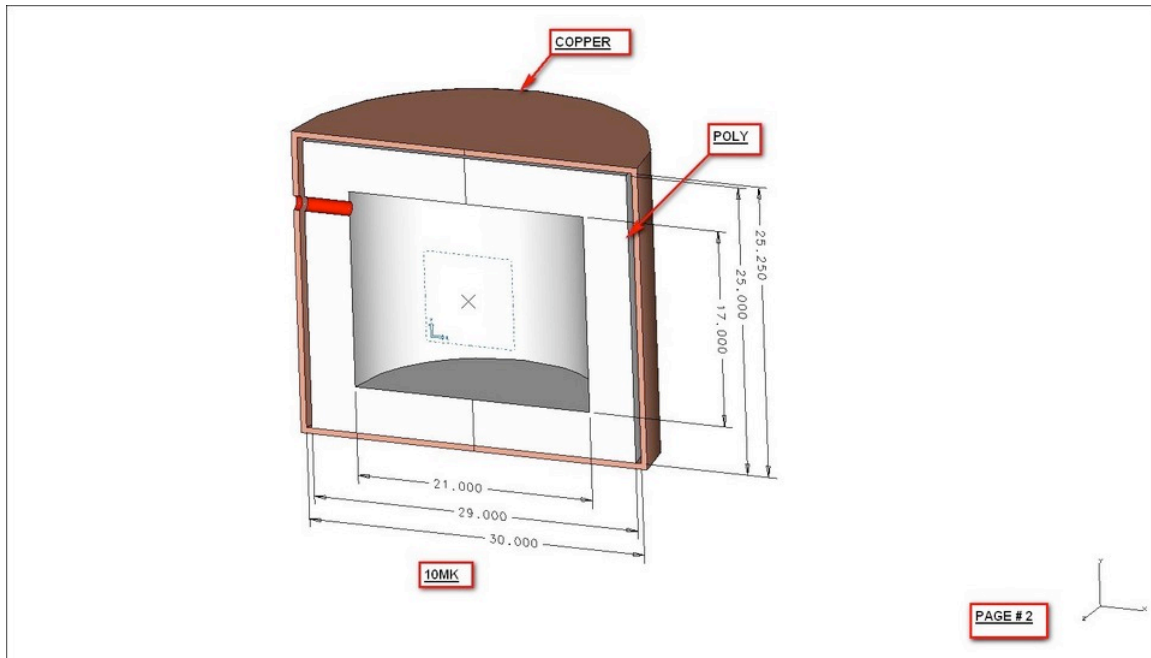


Figure 1: Proposed dimensions of poly shielding inside the MC (10mK) can.

Data for the specific heat of polyethylene was obtained from a paper entitled "Heat Capacities of Polyethylene from 2 to 360 K. I. Standard Samples of Linear and Branched Polyethylene Whole Polymer" written by S. S. Chang and A. B. Bestul. A curve fit was applied to data for linear polyethylene from 2.32 to 7.4 K. Below 2.32 K data points were added and the curve fit iterated until it looked reasonable.

The cooling power is provided by a 450 sccm flow of Helium 3. The density of He3 is 0.165 kg/m<sup>3</sup> which converts to a mass flow rate in the following manner

$$450 \frac{\text{cm}^3}{\text{min}} \times \frac{1 \text{m}^3}{10^6 \text{cm}^3} \times \frac{0.165 \text{kg}}{\text{m}^3} \times \frac{1 \text{min}}{60 \text{sec}} = 1.2375 \times 10^{-6} \frac{\text{kg}}{\text{sec}}.$$

### Heat Capacities of Linear Polyethylene

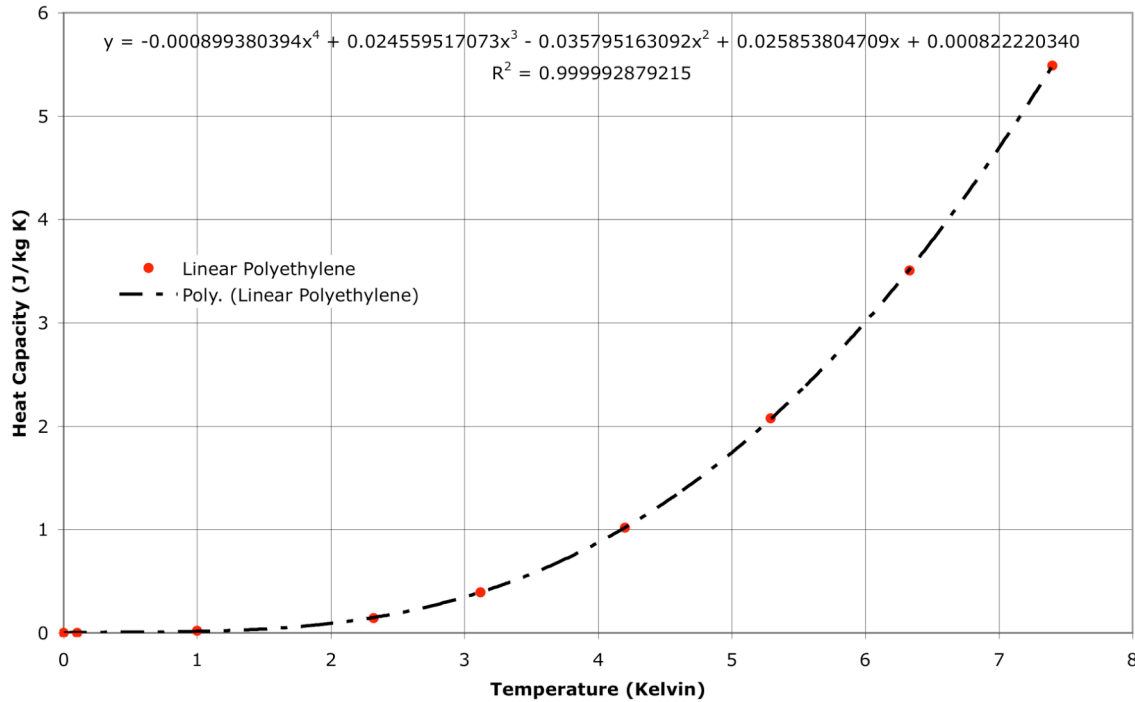


Figure 2: Polyethylene curve fit used for cool down estimates.

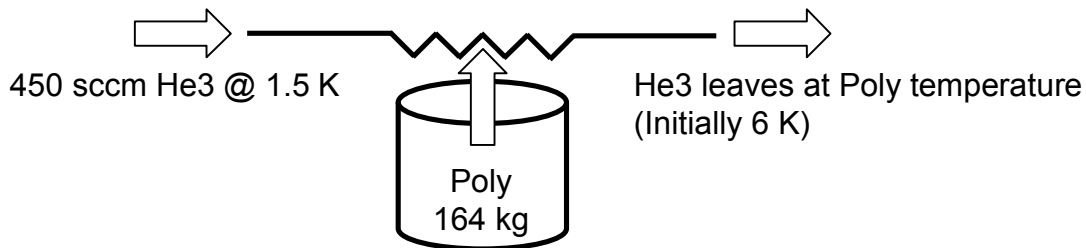


Figure 3: Heat transfer schematic.

The first calculation performed assumes that there is no thermal resistance between the poly cylinder and the He3 gas stream. In reality, there will be several bolted joints between the inner can and the He3 gas stream. Figure 3 shows the heat transfer mechanism. The poly dumps its heat into the He3 stream. The specific heat value used for the He3 gas stream was 5207 J / kg K and was estimated from He4. The specific heat of He4 is a very weak function of

temperature and pressure over the range of interest. The specific heat of the poly was estimated from the curve fit shown in Figure 2. The temperature range from 6 to 1.5 K was broken up into 0.1 K calculation increments to account for the strong temperature dependence of the poly specific heat.

An example calculation is shown below for the 6 K to 5.9 K poly cool down increment.

The specific heat of the poly is estimated as

$$Cp_{poly} = -0.000899380394 \left( \frac{6+5.9}{2} \right)^4 + 0.024559517073 \left( \frac{6+5.9}{2} \right)^3 - 0.035795163092 \left( \frac{6+5.9}{2} \right)^2 + 0.025853804709 \left( \frac{6+5.9}{2} \right) + 0.000822220340 = 2.9335 \frac{J}{kg \cdot K}$$

The energy required to reduce the temperature of the poly from 6 to 5.9 K is then

$$2.9335 \frac{J}{kg \cdot K} \times \frac{164 kg}{1} \times \frac{(6-5.9)K}{1} = 48.11J.$$

The time required to complete this cooling increment is estimated as

$$48.11J \times \frac{sec}{1.2375 \times 10^{-6} kg} \times \frac{kg \cdot K}{5207J} \times \frac{1}{\left( \frac{6-5.9}{2} - 1.5 \right) K} = 1682.7 sec = 0.467 hrs.$$

Figure 4 plots the poly cool down as a function of time. This “perfect thermal link” calculation predicts poly cool down from 6 to 1.6 K in 11.3 hours.

In reality, the poly will be poorly linked to the He3 stream. At these temperatures, “thermally engineered” flanges with substantial clamping force have a large thermal resistance. Efforts to thermally link the poly would likely result in much more resistance than found at the metallic flanges. In the Matlab thermal model, the “Soudan R121 – 5 Towers” set of inputs has 4 contact resistance values for the MC layer which sum to  $6.21 \times 10^{-5}$  ohms. Using the Weidman-Franz law this electrical resistance is converted into a thermal resistance.

$$K_{joints} = LT\sigma = 2.44 \times 10^{-8} \frac{W}{\Omega K^2} \times \frac{T}{1} \times \frac{1}{6.21 \times 10^{-5} \Omega} = 3.929 \times 10^{-4} T \frac{W}{K^2}$$

$$R_{joints} = \frac{1}{K_{joints}} = \frac{1}{3.929 \times 10^{-4} T} \frac{K^2}{W} = \frac{2545.1 K^2}{T W}$$

Figure 4 shows the simple heat transfer schematic for a poly cool down calculation that includes a thermal resistance.

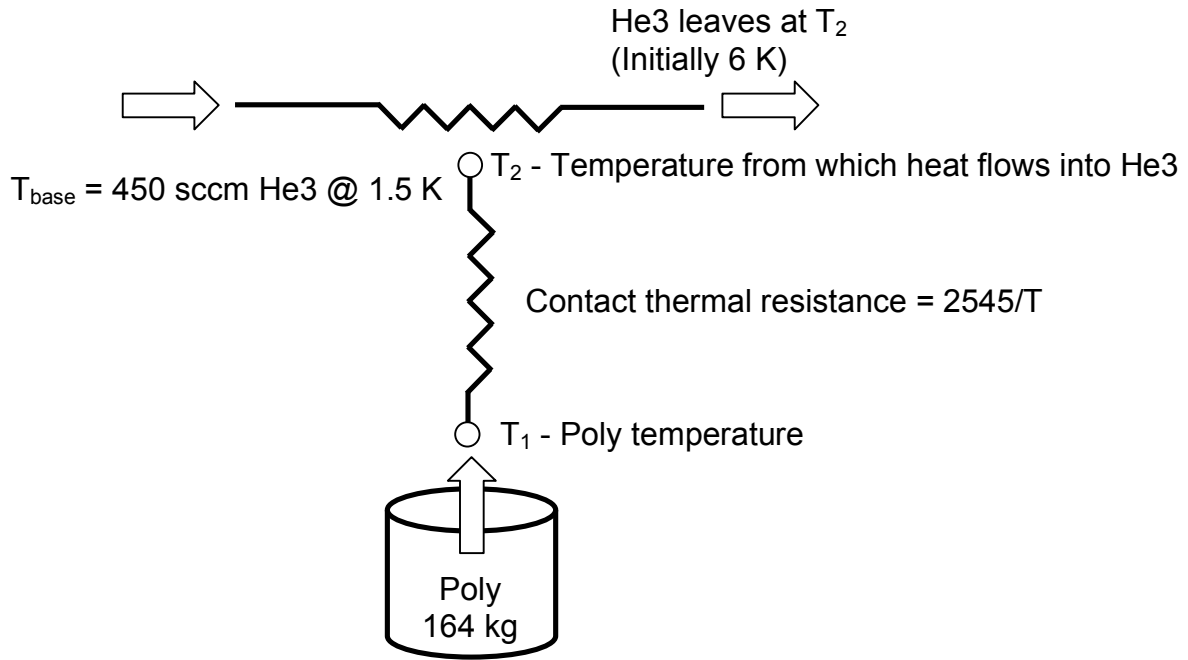


Figure 4: Heat transfer schematic with contact resistances.

To compute the poly cool down with a thermal resistance, the equations for heat flow to the He3 gas and heat flow thru the contact resistance are set equal to each other. The temperature the thermal resistance is computed at is the average of the temperatures on either side of the resistance.

$$\dot{Q} = \dot{m} \times C_{p_{poly}} \times (T_2 - T_{base}) = (T_1 - T_2) \times \left( \frac{T_1 + T_2}{2} \right) \times \frac{1}{2545}$$

These equations were solved in 0.1 Kelvin increments as the poly temperature decreased from 6 to 1.5 K. The cooling time for each increment was computed as the energy required to reduce the temperature 0.1 K based on the specific heat curve fit divided by the computed heat rate. The contact resistance addition increases the cool down time from 11.3 hours to 70.3 hours. Due to the fact that the thermal resistance between the poly and the MC layer copper will likely be much larger than the thermal resistances in the “engineered” flanges, the 10 day increase in the cool down time noted by Dan Baur seems reasonable. Figure 5 plots the cool down time for both poly cool down scenarios.

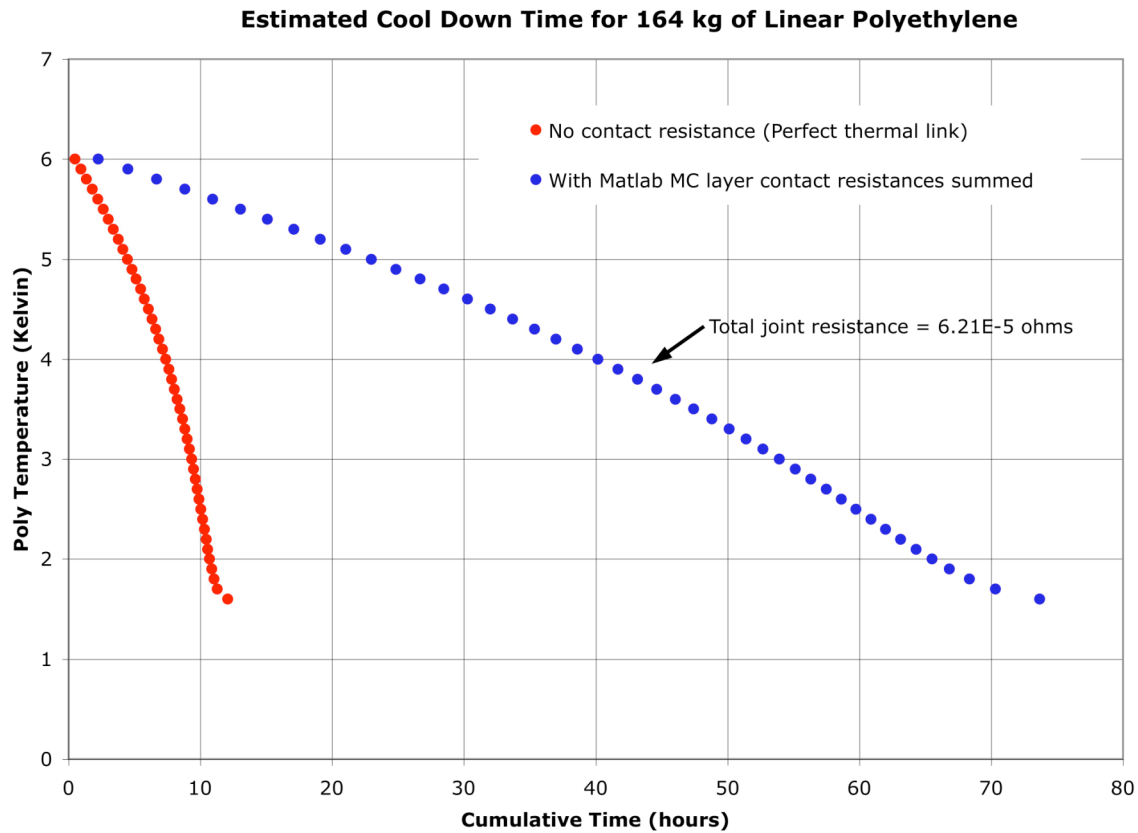


Figure 5: Polyethylene cool down curves.

Based on the previous estimates, the poly shielding will take a significant amount of time to cool down. Likely several times the 70.3 hours shown in Figure 5. This raises another question. Can the detectors cool down while the poly remains relatively warm?

The external surface area of the poly is

$$A = \pi \times 29 \times 25 + 2 \times \frac{\pi}{4} \times 29^2 = 3599 \text{ in}^2 = 2.32 \text{ m}^2.$$

The internal surface area of the poly is

$$A = \pi \times 21 \times 17 + 2 \times \frac{\pi}{4} \times 21^2 = 1814 \text{ in}^2 = 1.17 \text{ m}^2.$$

Because the OD of the poly is so close to the ID of the MC can, the radiation exchange will be modeled as exchange between large parallel planes. For this estimate it is assumed that the detectors inside the poly will have a surface area similar to that of the interior of the poly such that large parallel planes is again a good approximation. The following equations were used to estimate the heat rate into the poly:

$$\dot{Q}_{poly\_to\_MC} = \frac{\sigma A (T_{poly}^4 - T_{can}^4)}{\frac{1}{\epsilon_{poly}} + \frac{1}{\epsilon_{can}} - 1} \text{ and } \dot{Q}_{poly\_to\_det} = \frac{\sigma A (T_{poly}^4 - T_{det}^4)}{\frac{1}{\epsilon_{poly}} + \frac{1}{\epsilon_{det}} - 1}$$

Table 1 tabulates the heat flow from the poly to the MC can and from the poly to the detectors for various emissivities and poly temperatures. The MC can be gold plated to lower its emissivity ( $\epsilon_{can}$ ) into the 0.05 range. Gold foil could also be wrapped around the OD of the poly to lower its surface emissivity ( $\epsilon_{poly}$ ). At these low temperatures, the emissivity of the poly is likely much less than 1, but a more accurate number requires some research. Gold plating of the detector surfaces or the ID of the poly cylinder may be possible, but the backgrounds introduced by gold have not been quantified. For all calculations the MC can and the detectors are at 0.1 Kelvin. It is assumed that the poly can be thermally isolated from the MC can and detectors such that conduction is negligible compared to radiation.

Table 1: Estimates of thermal radiation rates from the Poly.

Heat flow to the MC can from the Poly						
Poly temp K	$\epsilon_{can} = 0.05$	$\epsilon_{can} = 1$	$\epsilon_{can} = 0.1$	$\epsilon_{can} = 0.2$	$\epsilon_{can} = 0.1$	$\epsilon_{can} = 0.05$
	$\epsilon_{poly} = 1$ microwatts	$\epsilon_{poly} = 1$ microwatts	$\epsilon_{poly} = 1$ microwatts	$\epsilon_{poly} = 1$ microwatts	$\epsilon_{poly} = 0.1$ microwatts	$\epsilon_{poly} = 0.05$ microwatts
6	8.530	170.608	17.061	34.122	8.979	4.375
5	4.114	82.276	8.228	16.455	4.330	2.110
4	1.685	33.700	3.370	6.740	1.774	0.864
3	0.533	10.663	1.066	2.133	0.561	0.273
2	0.105	2.106	0.211	0.421	0.111	0.054
1	0.007	0.132	0.013	0.026	0.007	0.003
0.5	0.000	0.008	0.001	0.002	0.000	0.000
0.1	0.000	0.000	0.000	0.000	0.000	0.000

Heat flow to the detectors from the Poly						
Poly temp K	$\epsilon_{det} = 0.05$	$\epsilon_{det} = 1$	$\epsilon_{det} = 0.1$	$\epsilon_{det} = 0.2$	$\epsilon_{det} = 0.1$	$\epsilon_{det} = 0.05$
	$\epsilon_{poly} = 1$ microwatts	$\epsilon_{poly} = 1$ microwatts	$\epsilon_{poly} = 1$ microwatts	$\epsilon_{poly} = 1$ microwatts	$\epsilon_{poly} = 0.1$ microwatts	$\epsilon_{poly} = 0.05$ microwatts
6	4.299	85.975	8.598	17.195	4.525	2.204
5	2.073	41.462	4.146	8.292	2.182	1.063
4	0.849	16.983	1.698	3.397	0.894	0.435
3	0.269	5.373	0.537	1.075	0.283	0.138
2	0.053	1.061	0.106	0.212	0.056	0.027
1	0.003	0.066	0.007	0.013	0.003	0.002
0.5	0.000	0.004	0.000	0.001	0.000	0.000
0.1	0.000	0.000	0.000	0.000	0.000	0.000

If the MC can is gold plated and the outside of the poly cylinder is wrapped in gold foil, the poly can be at 6 K and only radiate 4 microwatts to the inside of the MC can which is at 0.1 K. The amount of heat radiated from the poly drops quickly as the poly temperature falls due to the fourth power dependence. If either the inside of the poly or the detectors can be covered in foil or gold plated, the heat input from warm poly will be acceptable. If no gold can be inside the

poly due to background considerations, then some more analysis may be required. A couple of very thin copper sheets installed as radiation shields could reduce the thermal radiation from the poly if gold inside the poly is an issue.